“The Golden Triangle and the Future of Health Care”
Remarks of NASA Administrator Daniel S. Goldin
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Good evening. Thank you for being here as we kick-off this historic NASA/NCI collaborative working group. And as I look around this room, I see the best and the brightest people the world has to offer. I want to personally thank each of you for your commitment to revolutionizing health care.

Before I begin, I want to thank David Baltimore for his leadership at Cal Tech. Since I know he’s bringing the same level of dedication to this workshop, I am confident we have an outstanding and productive meeting ahead of us.

I would also like to salute Rick Klausner for the incredible job he does at the National Cancer Institute. He led the way in strengthening the partnership between NASA and the NCI, and the American people are the ones who benefit from it.

Some people may wonder what NASA and the NCI have in common. Well, our missions are a lot alike. No, that doesn’t mean Rick Klausner is going to the moon. And, no, Rick wasn’t the model for the Face on Mars. But it does mean that NASA and the NCI share a deep concern with keeping people healthy.

Henry Ford once said that, “Coming together is a beginning, staying together is progress, and working together is success.”

Well, I am glad NASA and the NCI are coming together in this effort, because I believe this partnership gives us an incredible opportunity to protect people’s lives.

Today, I would like to talk first about where NASA is now and then focus on where we want to go in partnership with the NCI.

Obviously, NASA’s primary concern is with the health of our astronauts. Our spaceflight crews rely on us to ensure their health and safety at each phase of every mission.

That’s why we carefully assess the potential risks and identify methods to eliminate or minimize them. While we can control risk in many areas, we are most concerned about areas where we have only minimal control – like the hostile environment of space.

Radiation in space has a major impact on all NASA activities, and radiation protection is one of the most important features of our future spacecraft and missions. We at NASA have an absolute obligation to mitigate the risks of acute and long-term radiation exposure.

Along that front, we are enhancing shielding designs for the International Space Station, and we will use the Station to test and validate other physical mitigation concepts. We also plan to deploy an array of solar sentinels to establish an advance warning system for solar events.

We also want to use advances in molecular and genomic research to develop a prophylactic radiation vaccine or a periodic radiation antidote. These therapies could enable a crewmember to initiate molecular level repair mechanisms and mitigate acute or chronic radiation exposures.

We carefully screen applicants and only select the most medically qualified as astronauts, but we know that potentially life threatening injuries and illnesses can and will occur in space. Our current approach to serious illness or injury is stabilization and return to Earth.

Right now, we can return to Earth from low Earth orbit within 12 to 24 hours, but return is not an option for long duration space flights beyond low Earth orbit.

Think about it.

The closest planetary body to Earth is the moon, and it is a three-day trip. And we measure trip time to Mars in months. Once we leave Earth orbit and commit to Mars, we cannot just turn around and come back if something goes wrong or someone gets sick – orbital mechanics do not allow that. We can cut the trip short, but it could take as long as years to get back to Earth.

And there is no local emergency room along the way to rendezvous with for a quick CAT Scan or MRI, or even routine blood work.

We must provide crews with the tools to respond to sudden trauma and acute illness in space. They need advanced, accurate diagnostics and the ability to perform complex surgical intervention when appropriate. These macroscopic tools and therapies must work within a complex human-machine interface in the limiting confines of a spacecraft and in microgravity, where loose material and fluids will float freely about.

That's why our clinical care system must be highly autonomous, with exhaustive on-board expertise available either virtually or in actuality. Whatever expertise we need for an immediate medical response must be with us – either as part of the crew or built into the systems we send with them. It must also minimize open surgical procedures. In fact, we must develop methods to minimize all intrusive procedures.

Consultation with Earth-based resources will be of very limited value due to a one-way transmission time of up to 20 minutes from Mars to Earth. A medical emergency could become a tragedy in that time span.

Successful long duration missions – 3 to 4 years for a mission to Mars or Europa, a moon of Jupiter – will depend on development of countermeasures to the effects of microgravity on skeletal, muscular, neural, and immune systems as well as early disease detection and effective treatment. We will need to constantly and precisely monitor indicators including hormones, neurotransmitters, organ-specific enzymes and metabolites in order to identify and treat clinical and psychological conditions.

In the confines of a spacecraft, a macro approach to medicine may not always be possible. That's why we also need to consider a combination of macro and nano approaches. For instance, nano devices might communicate among each other, or they might communicate to more powerful diagnostic tools located outside the body.

Given these daunting challenges, NASA must develop and exploit revolutionary technology to maintain crew health and make space-based clinical care truly space-based. Enhancing our understanding of human health issues is critical.

That's why NASA is excited about our collaboration with the National Cancer Institute. Together, we seek to deliver powerful medical and technical tools across the globe and throughout the Universe. NASA and the NCI's shared goals of effective health monitoring, early disease diagnosis, and non-intrusive targeted therapy will drive significant advances in human health care.

As we gain insight into the molecular basis of physiological processes, the efficiencies of physiological resource utilization, and the speed of physiological information processing – all nanoscale events – we should be able to develop the detection, diagnostic, and treatment technologies we need.

Imagine having nano-sensors, nanodiagnostic systems, and nanotherapists.

We could put tiny nano-explorers into the body with a nasal spray, a patch, a pill, or a small needle. These extremely small devices would travel throughout body tissues, monitor health conditions, and detect molecular signatures of disease when they appear. The data the nano-explorers compile would be analyzed using advanced information technology capabilities to provide instant and accurate diagnosis—not to replace humans in the health care loop, but to complement human intelligence and insight.

Nano-therapist devices might then target the source of the ailment and eliminate the disease. The advances this NASA/NCI partnership will strive to bring about in identifying disease signatures at a sub-cellular level, capturing and analyzing these data signals, and delivering tailored treatments could revolutionize the speed and effectiveness of basic health-care here on Earth.

The urgency of developing these capabilities was driven home again recently. Who can forget the Antarctic scientist who discovered a lump in her breast? While she managed a diagnosis with telemedicine, attempts to deliver medical supplies to her failed and treatment required her return to a medical facility.

It didn't happen overnight for her. Antarctic winter prevented an immediate med-evac flight, so she was forced to wait and worry for months. And that was here on Earth!

That is unacceptable for her, and clearly, this will not be an option for our crews as they move beyond low Earth orbit.

So how do we get to where we need to be?

At last year's NASA/NCI meeting I gave you a broad vision of the impact I believe biology will have on NASA's future missions and Rick Klausner gave you the vision for the future of human health care. Not surprisingly, we came to many of the same conclusions. Today, I believe in that vision more than ever, and I want to be more specific about what we need to do to achieve our shared goals.

First, let me tell you a little bit about where we stand on the three key technologies that will form the cornerstones of much of our future technology: nanotechnology, information technology and biotechnology.

I like to call it the Golden Triangle.

Unfortunately, some people insist on spelling it G-O-L-D-**I**-N.

But no matter how you spell it, we at NASA do not view these three technologies as independent from each other. Biological processes are inherently designed, built and operate at the nanoscale – atom by atom, the ultimate in miniaturization. Single cells perform the work of entire chemical factories. The information contained in a DNA molecule is a billion time more dense and energy efficient than anything we can build out of silicon. And the model of the ultimate thinking computer is the brain.

Despite this, we have serious barriers to overcome before we can release the full potential of this triad.

Today we are less than a decade away from hitting the "brick wall" of conventional micro-miniaturization. Using the best technology available, we can mass-produce microsystems with feature sizes of about one tenth of a micron. Advanced lithography may achieve a resolution below a tenth of a micron but this is still 100 to 1000 times greater than the atomic scale.

A computer capable of completing a trillion operations per second using today's microelectronics would consume on the order of a megawatt of electricity. However, the unique computational engine we call the human brain consumes less than a watt of power while operating at unbelievable speeds.

Although a one-for-one comparison is really not possible, the performance of the brain is well beyond any performance conceivable from today's best super computers.

This amazing performance is due mainly to the brain's massively parallel processing and nature's advanced algorithms.

To emulate this magnificent engine, it is clear we will have to transition from the silicon-based binary computational designs of today to those based on quantum physics, DNA, protein or hybridization, or, more likely, a combination of the best features of each.

This is what I mean when I talk about power and speed for the future.

Our challenge is to learn how to make these revolutionary new devices cost effective and reliable. The answer does not lie in chipping away material atom by atom, but by building it up, atom by atom. This is NASA's view of nanotechnology.

In searching for ways to do this, we have found the answer is all around us. Biological process have operated at the atomic scale since the beginning of life on Earth. Modern lithography exploits the technology of photography to mass produce circuitry at the micron scale.   And biology functions on an even grander scale through self-reproduction, self- assembly, and the ability to adapt and specialize to respond to a dynamics environment.

However, when we look at these systems at the atomic scale, they are merely a collection of individual, uninteresting atoms. Biological capabilities of molecules, membranes and cells cannot be extrapolated from the properties of the individual atoms – yet we know the structure of the atom in fine detail and we can model them with near perfect accuracy. Only as atoms assemble into complex structures do spectacular properties and capabilities emerge.   As the simplest of biological structures combine into more and more complex forms, they begin to become intelligent.   They can distinguish between structures that differ by a single atom or which have the slightest difference in topology.

When we think of information we also think of the digital revolution. But biology is the ultimate in digital technology. Atoms work together to form complex molecules. Groups of molecules perform more complex operations. And the complex molecules assemble into higher level building blocks – cell membranes, internal structures and DNA—the subcomponents of a cell. Chemical and electronic communications between cells enable the components to come together and work as an integrated system.

This same hierarchy applies to how we design and build our current information systems – software and computers. The microchips that are so ubiquitous in our daily lives are built from millions of simple electronic gates assembled into computational cells that are laid out in complex circuits. The software we use to control them is built byte by byte from individual keys strokes – each like a single atom -- to form lines of code – a software molecule - that form computational modules that, in turn, form complex code.

In the end, we have millions of lines of code -- tens of millions of key strokes – that only have useful meaning when the hardware/software system is taken as a whole.

And here comes the critical distinction between biological systems and current computers. Today's computers may seem to come to life when we use them, but they can only adapt, evolve and think to the extent we anticipate the environment and operating conditions they will encounter and build in appropriate response mechanisms.

As we develop the technologies of the future, we will extend this paradigm to all of our space and aeronautics systems. We will build them – conceptually, analytically and physically -- from the atomic scale to the macro-scale. We will build into them the sensory capability to be aware of a dynamic environment, the intelligence to determine how to respond to it and the adaptability change in form and function.

This will begin at the smallest scale, such as in the fundamental building blocks for smart materials -- materials with imbedded nano-scale sensors, computational elements, and actuators – and extend upward to entire vehicles, spacecraft and aircraft.

NASA's role is to focus on the zone of convergence formed by the overlapping domains of nanotechnology, biotechnology and information technology. And, in particular, to focus on the center of the zone where the synergy between the three becomes much more powerful than the individual technologies. The zone below a technology event horizon where sophisticated properties of complex systems dissolve into simply discrete atoms.

This is the region where we must learn to design and build these complex, intelligent systems and to predict their properties and behavior.

By combining the NCI's expertise in biochemistry, molecular and cellular biology, as well as clinical medicine with NASA's expertise in physical micro-systems and biotechnology we can develop the fundamentals for an entirely new technology discipline. Biologically-based processes will form the basis for the design, fabrication and operation of nano-scale devices and integrated micro-scale systems.

We need to focus on and exploit six specific features of biological systems: selectivity and sensitivity at the atomic scale; the ability of single units to massively reproduce with near zero error rates; the organization capability to self-assemble into highly complex systems; the ability to adapt form and function to changing conditions; the ability to detect damage and self-repair; and an ability to communicate among themselves.

Our scope will be to develop the fundamental technology to design and build useful biology-inspired systems that have these attributes. However, both NASA and the NCI have specific missions to accomplish and our joint activities should be clearly directed towards accomplishing those missions.

Some of what we make will be completely biological, such as thin, protective films to protective sensitive material from harmful UV-- this could include our own skin -- or we could make sensor arrays to detect single molecules. Some of what we make will be inspired by biology – such as neural networks that mimic the function of the brain. But mostly we will use the best of both worlds to make hybrid systems.

For example, consider multi-functional materials that have different layers for different purposes. The outer layer would be tough and durable, capable of withstanding the harsh environment of space, but it would also have an embedded network of sensors to measure temperature, pressure and cumulative radiation exposure.

When the surface temperature became too hot, the sensors would trigger a response in the outer surface of the material to change reflectivity and cool the surface. If it got too cold, the reverse would occur. It would also transmit this information to other parts of the spacecraft.

The next layer down could be an electrostrictive or piezoelectric membrane that worked like muscle tissue. A network of nerves would stimulate the appropriate strands and provide power to operate them. If a rise in the radiation dose rate was sensed, an alarm would be issued.

And the base layer could be a highly plastic layer that would sense any penetrations or tears and flow into any gaps. Ideally, it would trigger a reaction in the damaged layers that would initiate a self-healing process. Also, damaged sensors, electrical carriers or actuators would be bypassed and the network would automatically reconfigure to compensate for any loss of capability. What we would have is a smart, functional, durable material that could be used to cover the outside of spacecraft or used to make space suits for astronauts.

Or consider making a neural network that uses actual neurons to create the network. We could immerse them in a fluid or jell to allow a 3-D structure to arise as hippocampal neurons form natural links to each other during the learning of a particular process.

Such a network would function like a very simple brain, but it would also be just as fragile. Unfortunately, this network could never survive in the harsh environment of space without extensive protection. However, if we overlaid or substituted different materials for the biological materials in the neurons, we could evolve the biological network into a space durable network.

Today we have activities under way to research the development of materials based on single-walled carbon nanotubes – single molecules a nanometer in diameter and about a micron in length. They are up to 100 times stronger than steel and just 1/6 the weight. Variations of these tubes can form nanometer-scale wires with 100,000 times better current carrying capacity than copper.

And in another form, they might be semiconducting and could be configured as digital electronics. If we can grow these tubes with the right properties and assemble them into the right kinds of networks we can reduce the size of microelectronics by a factor of at least 10,000.

We might make the nanotubes in chemical reactors, by laser ablation or by chemical deposition. And we might manipulate them in a chemical solution, with magnetic fields or by pushing them around, one by one with other nanotubes. However, they are basically large carbon molecules and we should be able to make them and assemble into networks biologically. We may engineer a cell to manufacture nanotubes and enzymes to seek out and separate the different kinds of tubes. The equivalent of antibodies could tag the tubes and an analog to DNA could control how the different kinds of tubes assemble.

So where could this partnership between NASA and the NCI take us?

Sensors based on biological designs and nano-scale electronics could be smaller than an individual cell. They could be inserted into the human body with imbedded nano computers and used to control sub-micron chemical analyzers.

The information developed could be stored in molecules modeled after RNA and tagged to identify precisely where it came from. We could replicate these intelligent little systems so they can work throughout the body. They could be made sensitive to specific diseases or agents– artificial anti-bodies – and only begin functioning when the intended conditions were encountered. We could also make them sensitive to a specific radio frequency digital code and turn them on or off on command.

NASA has been supporting research and development in a number of areas that will serve as building blocks for future advances in developing bio-molecular nanoscale healthcare technologies.

To highlight just a few…

- Molecular motors using the same energy source used by living cells have been built to sort and distribute materials to target cells.
- Nerve cells have been grown on silicon chips to influence information processing flow.
- Blood analysis laboratories have been created on a single silicon chip.
- Non-invasive blood chemistry analysis techniques can measure pH, electrolytes, and hematocrit levels in blood.
- Sensors with the same design and size as the hair cells in the inner ear have been micromachined. These carbon nanotubes could serve as the basis for a variety of applications including accelerometers, micro gyroscopes, flow sensors, tactile sensors.

As final example of what can happen when the right people get together for the right reasons at the right time, let me tell you a little more about carbon nanotubes.

About a year and half ago, NASA started to work with researchers to produce carbon nanotubes for structural applications.

At the time, the best available production process was measured in milligrams per day and the cost in thousands of dollars per gram. Since that time, an entirely new production process has been developed and demonstrated. And this year we expect to demonstrate continuous production at the rate of up to 100 grams per day of high walled carbon nanotubes in a small laboratory scale reactor.

After that, the process may be ready for commercialization. We hope to accelerate production from quantities of thousandths of a gram per day to thousands of grams per day in about two years.

There is every reason to hope for similarly spectacular achievements in our joint effort.

The connection between NASA's vision for developing health and safety capabilities for exploration missions and NCI's vision of developing early detection, diagnosis, and treatment of cancer is clear.

We have agreed to jointly develop and implement a scientific and technological planning process to define areas of opportunity. Together, we will develop the necessary infrastructure to promote scientific progress, and we will define, fund, and manage research projects and programs in relevant fields. And finally, we will commit to exchanging relevant technologies as they are developed.

The cross-disciplinary approach we are starting today will be a model for the next generation of scientists. They will be inspired by our commitment to placing the public good above all other concerns. And our example will show them the benefits of close cooperation and collaboration.

NASA begins a collaboration with the National Cancer Institute, to harness the molecular miracles I have mentioned for meeting the human challenges of space travel. NASA brings decades of innovations, including amazing miniaturizations or nano-technologies, remote monitoring, sensor technology, and complex data collection. NCI brings world-class leadership in biomedical research, bio-informatics and the molecular characterization of disease.

Today we take the first step—coming together. And in the coming days and weeks, we will show Henry Ford's wisdom as we make progress by staying together and achieve success by working together.

This working group is an essential part of the process. The results of this meeting will impact people throughout the world…and far into the universe. Let's get to work!

Thank you very much.